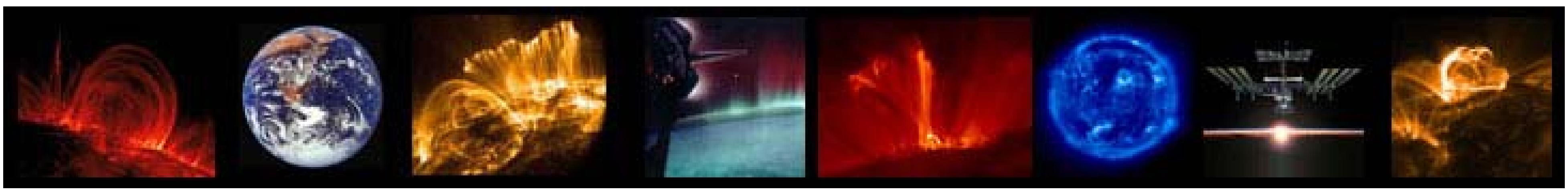
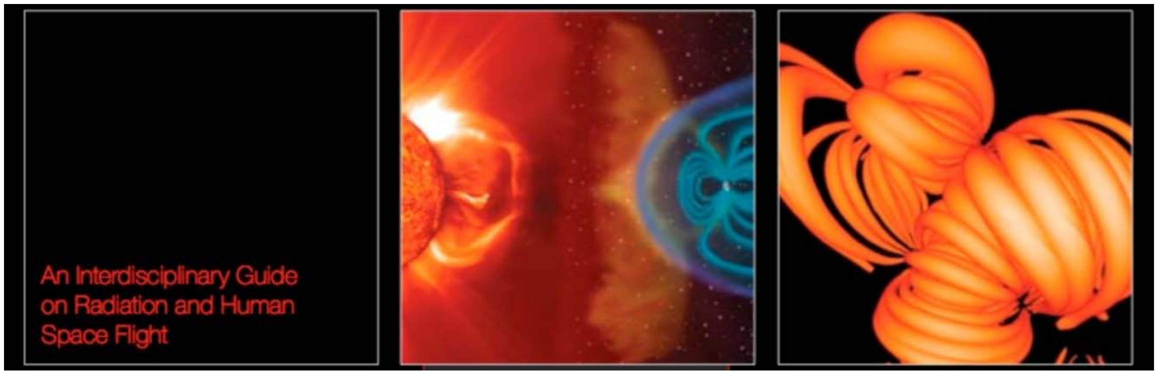
National Aeronautics and Space Administration

Space Faring: The Radiation Challenge



Space Faring: The Radiation Challenge

- What is space radiation?
- What kind of radiation is harmful?
- Where does space radiation come from?
- What are the health risks of radiation?
- How can we protect astronauts?



What is Space Radiation?

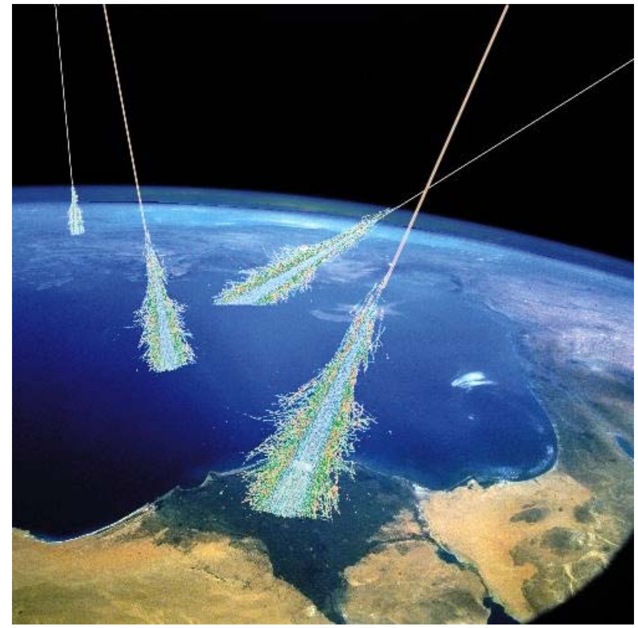
- There are two types of radiation:

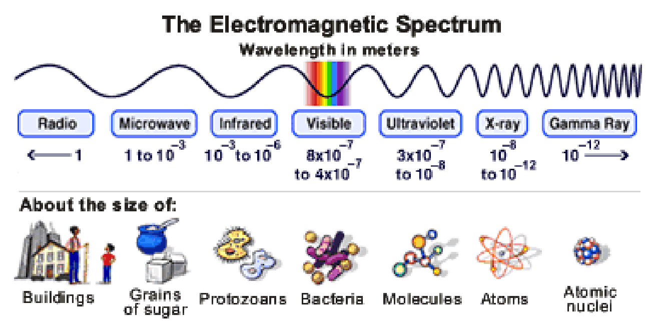
(1) Particle Radiation

Atomic nuclei moving at very high speeds

(2) Electromagnetic Radiation

Radio, microwave, infrared, visible light, ultraviolet, x-rays, and gamma rays.





What Kind of Radiation is Harmful?

- Ionizing Radiation - higher energy

  This type of radiation can remove electrons from the atoms of a material through which it passes. Metal, fabrics, and even human tissues can “ionized” by ionizing radiation.

  Both particle and electromagnetic radiation (EM) can be considered ionizing radiation if it has enough energy. Examples of EM radiation that are ionizing include x-rays and gamma rays. Galactic cosmic rays are examples of particle radiation that is considered ionizing.

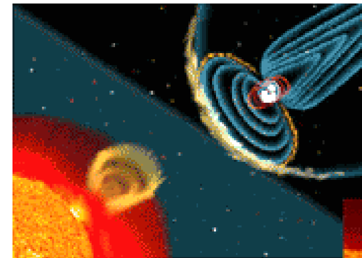
- Non-Ionizing Radiation - lower energy

  Examples of non-ionizing radiation include radio waves, microwaves, infrared waves, and visible light. While many forms of non-ionizing and ionizing radiation are part of our everyday life, each can cause damage to living things, and precautions are necessary to prevent unnecessary risks.

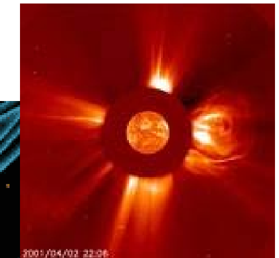
Where Does Space Radiation Come From?

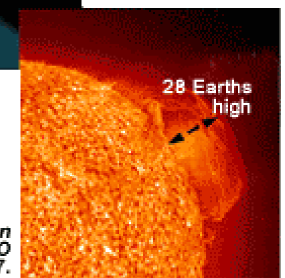
- ## The Sun

  produces both particle and electromagnetic radiation (EM). Eruptions of particles that stream from the sun into space are called solar particle events. Examples of these events include solar flares and coronal mass ejections (CME), which move through space at speeds over 1,000,000 km/hr . They are potentially dangerous to robotic and human space explorers.



An illustration of Solar Coronal Mass Ejection and its influence on our planet.

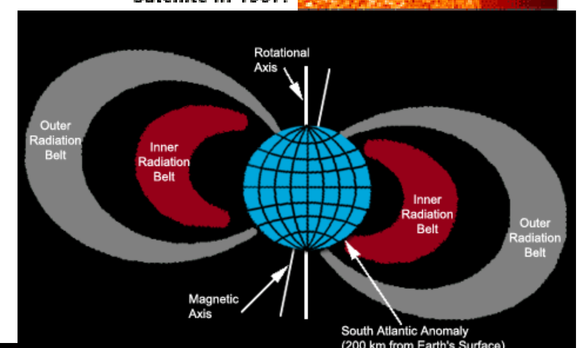




An activity on our Sun as seen from the SOHO satellite in 1997.

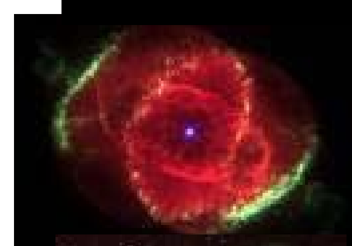
- ## Geomagnetically Trapped Radiation

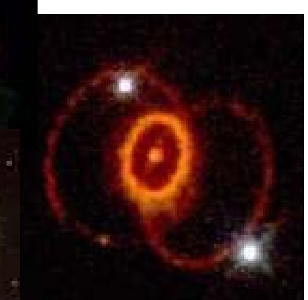
  Electrons and protons trapped in Earth's magnetic field make up the radiation belts known as the Van Allen Belts.

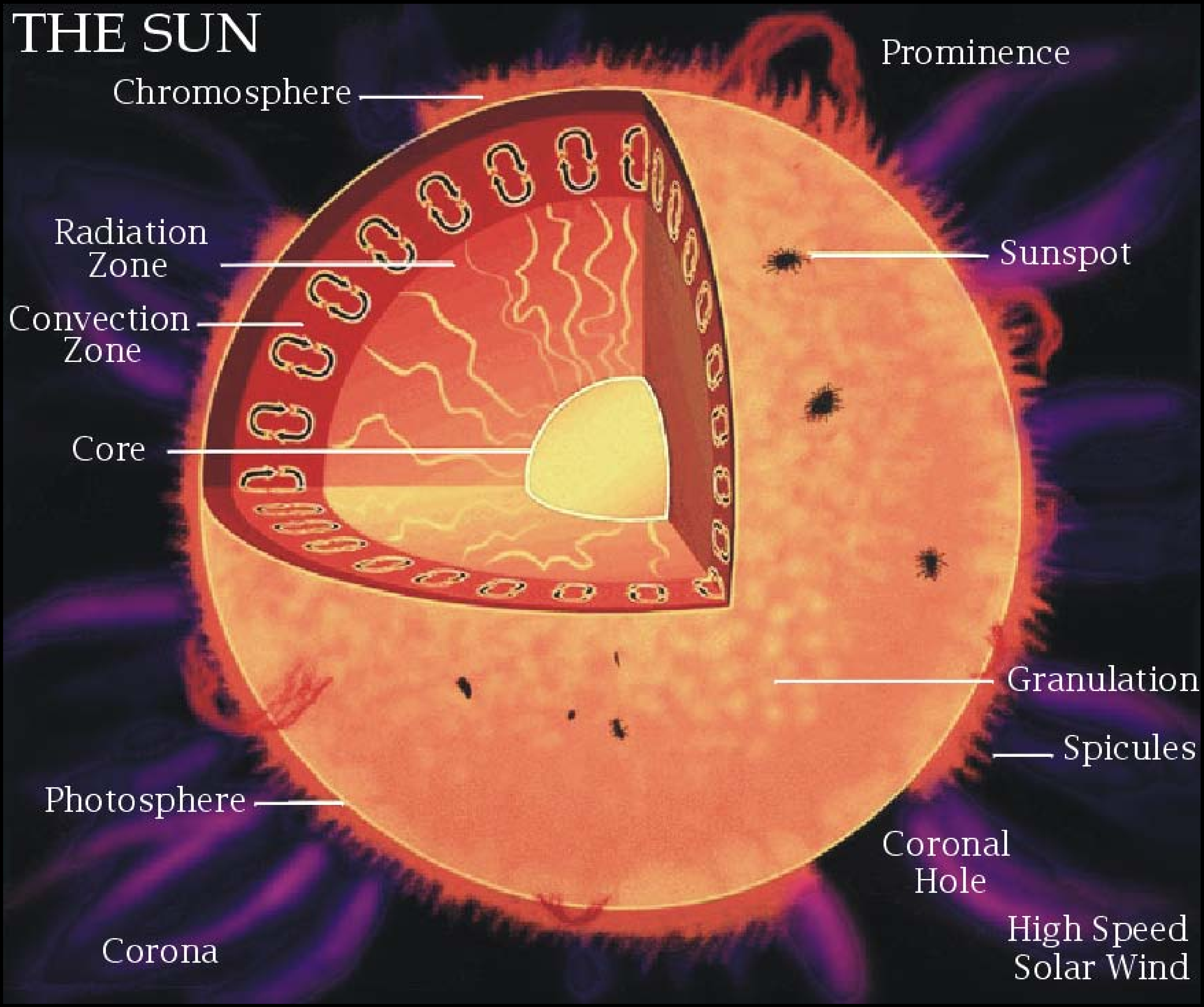


- ## Galactic Cosmic Rays

  Particles that move at speeds close that of light (much faster than a CME). Examples include electrons, positrons and atomic nuclei such as hydrogen, helium and heavier elements. Originate from supernovae remnants.





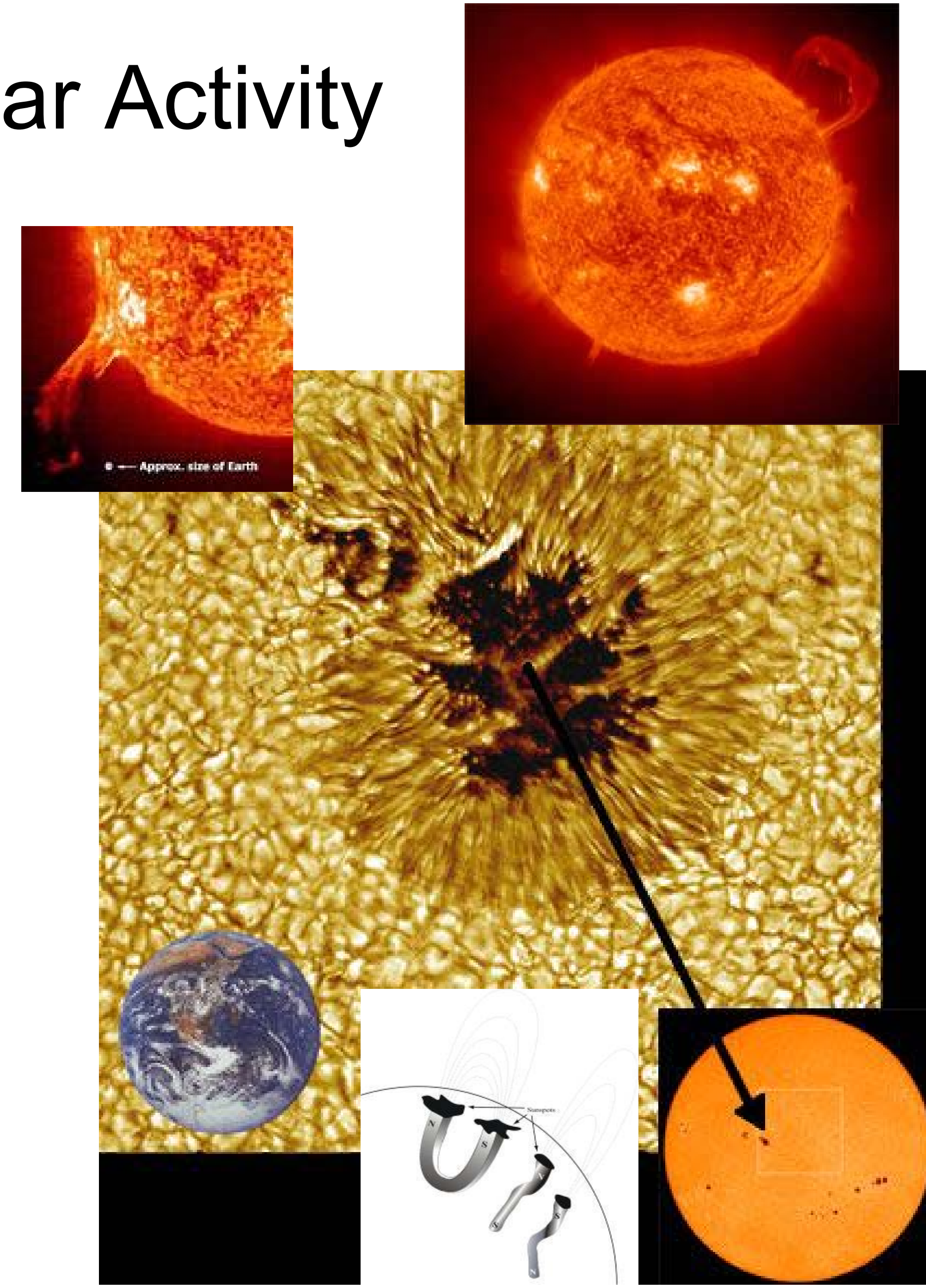

THE SUN
Chromosphere
Prominence
Radiation Zone
Sunspot
Convection Zone
Core
Granulation
Spicules
Photosphere
Coronal Hole
High Speed Solar Wind
Corona

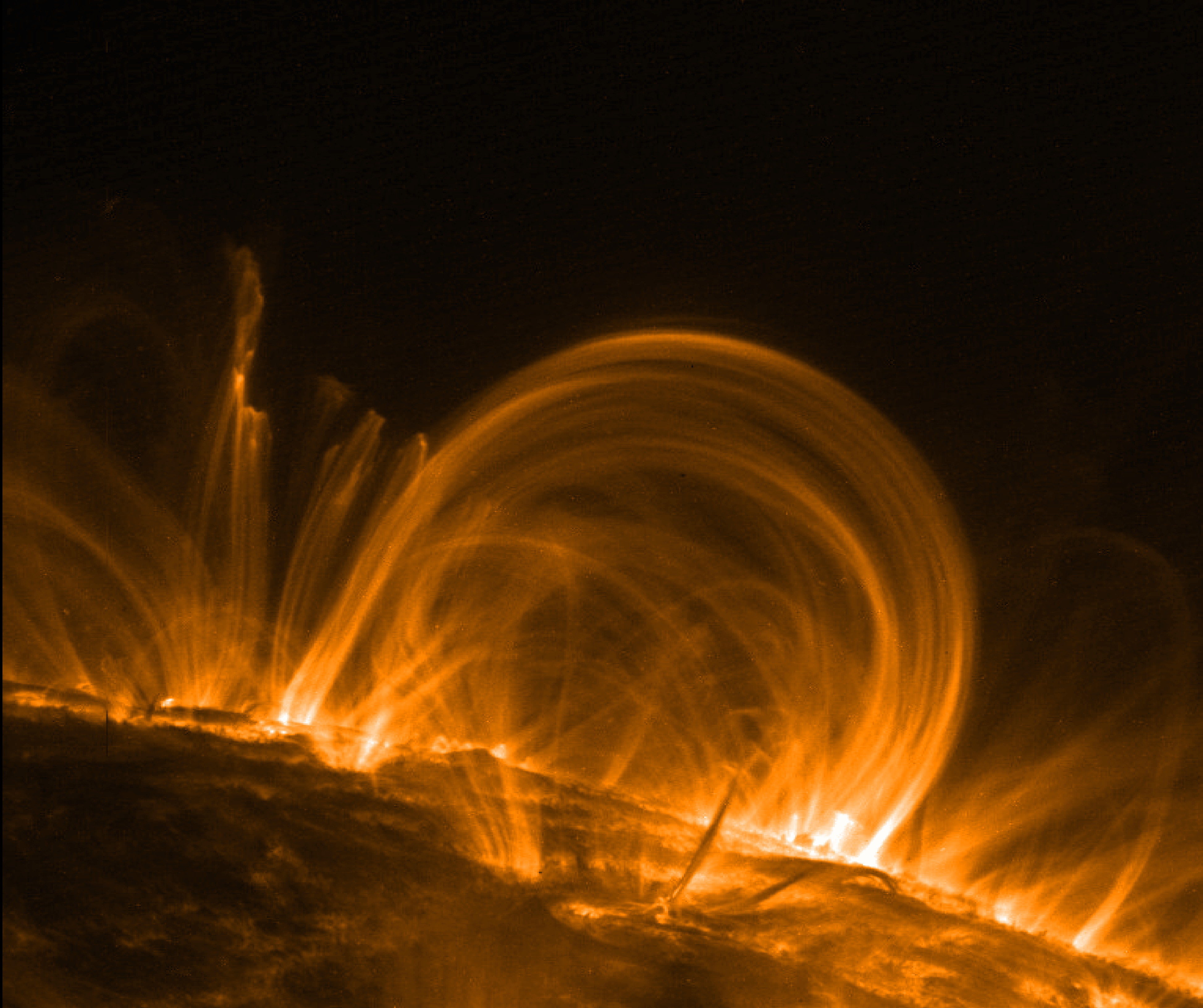
Sunspots: Clues to Solar Activity

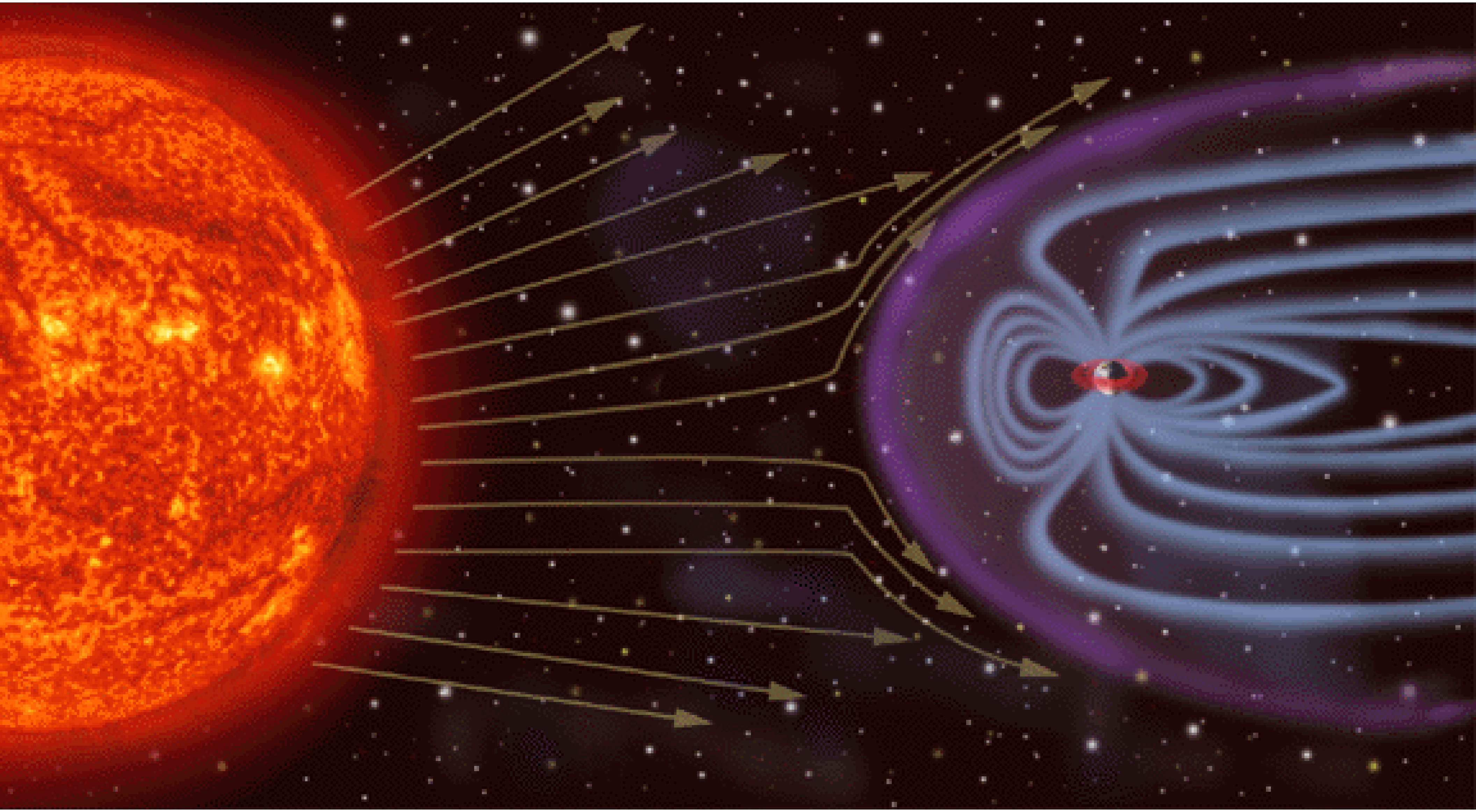
- Sunspots are cooler areas on the surface of the sun that can be larger than the Earth in size. They mark locations where magnetic field lines loop in and out of the Sun’s surface. Many sunspots indicate an active Sun. Few to no sunspots indicate a less active Sun.

- When the Sun is active, its overall magnetic field is more chaotic and thus more effectively shields the solar system from the galactic cosmic radiation streaming through interstellar space.

- During periods of increased activity, Coronal Mass Ejections (CME) or eruptions of plasma consisting mainly of electrons, protons, and small quantities of heavier elements, are more common than during periods of reduced activity.







Earth’s magnetic field (blue lines) and atmosphere protects us from the solar wind (arrows), Coronal Mass Ejections, and galactic cosmic rays. The red torus that encircles the Earth represents the radiation belts of geomagnetically trapped particles.

What are the Health Risks of Radiation?

- When astronauts travel into deep space, they leave the Earth’s protective atmosphere and magnetic field, and are exposed to space radiation. High energy particles (from solar CMEs and GCR) can be highly penetrating and ionizing to both tissues and spacecraft.
- As ionizing space radiation passes through biological tissue, it can cause damage the DNA of a cell.
- Particle radiation such as GCR heavy ions like iron can actually knock pieces out of a molecule of DNA.
- Dislodged particles from the ion track can shower off into neighboring tissues causing more damage.

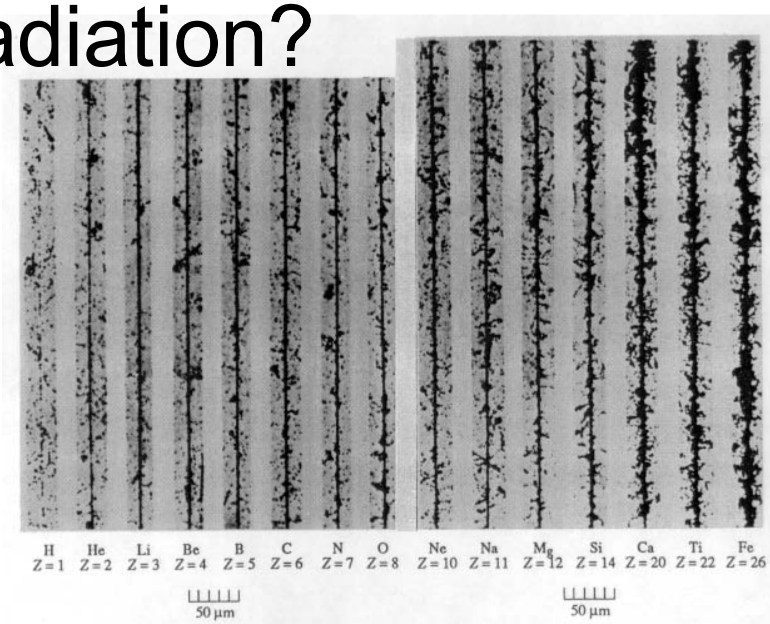
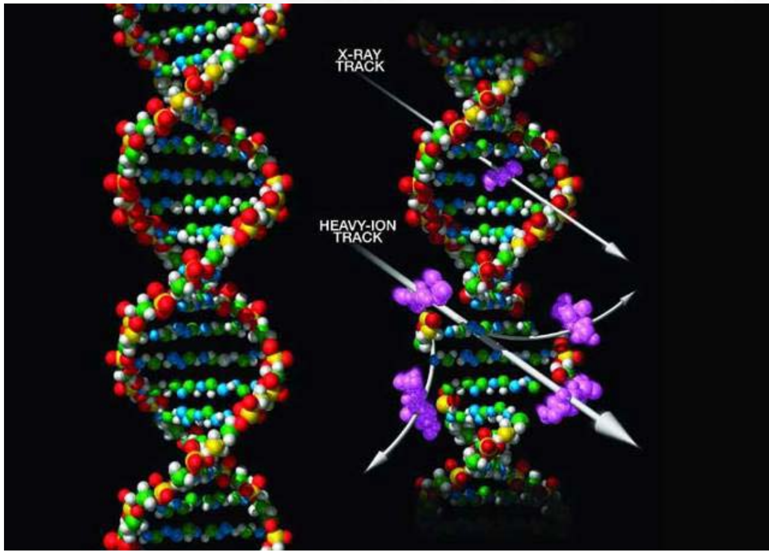
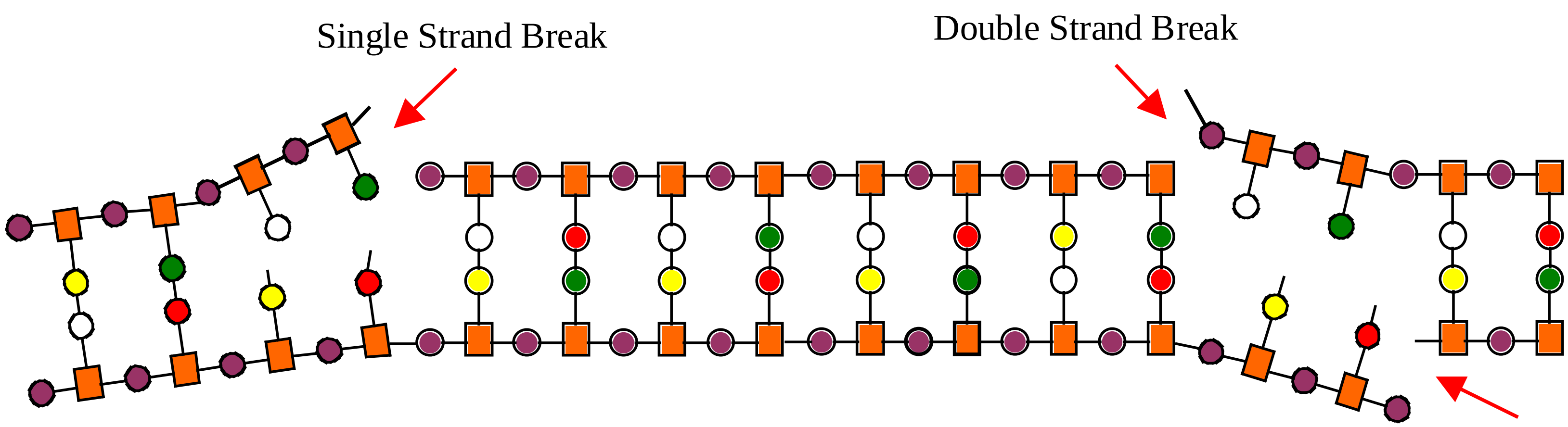


Figure 1.18. Cosmic-ray ion tracks in nuclear emulsion. (Taken from McDonald, 1965.)

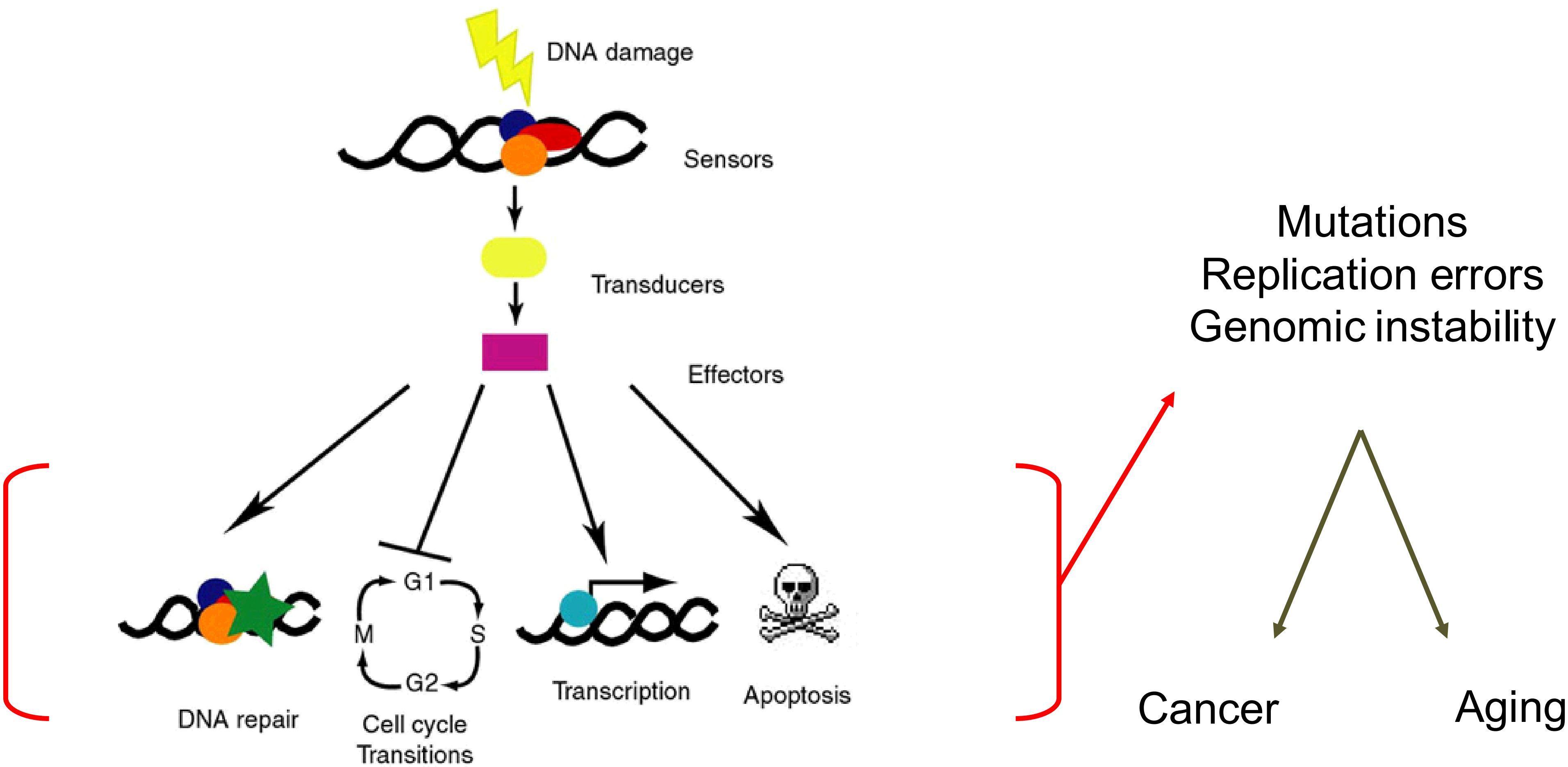


Modeling the Effects of Ionizing Radiation on DNA

- **Single Strand Breaks -** can be repaired by enzymes designed to repair DNA
- **Double Strand Breaks -** often lethal to a cell because it cannot be as easily fixed by the repair enzymes
- Below is a model of a radiation-damaged DNA molecule with single and double strand breaks.



Consequences of Radiation Damaged DNA



Smith J., Smith K. and Mézard C.. Tying up Loose Ends: Generation and Repair of DNA Double-Strand Breaks
Atlas Genet Cytogenet Oncol Haematol April 2001.

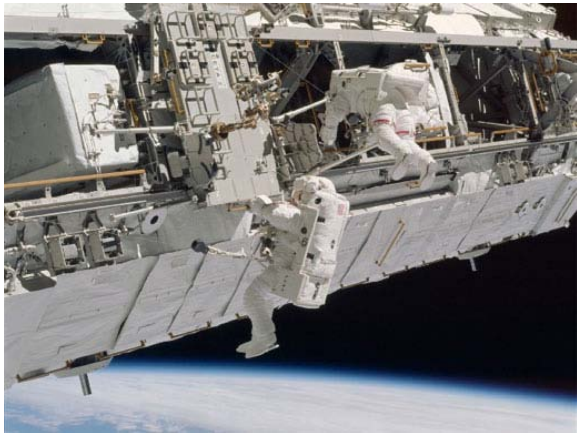
Examples of Health Effects from Acute Radiation Exposure		
Exposure (mSv)	**Acute Health Effects**	**Time to Onset (without treatment)**
Less than 100	no detectable health effects	
Above 100	cell and chromosomal (DNA) damage	hours
Above 1000	nausea, vomiting, diarrhea: prodromic syndrome	1 to 2 days
Above 1500	Damage to blood-forming organs: hematopoietic syndrome; possible death	~1 month
3000	50% death from hematopoietic syndrome	in 30 to 60 days
10000	destruction of intestinal lining	
	internal bleeding	
	Death	1-2 weeks
20000	damage to central nervous system	
	loss of consciousness	minutes
	death	hours to days

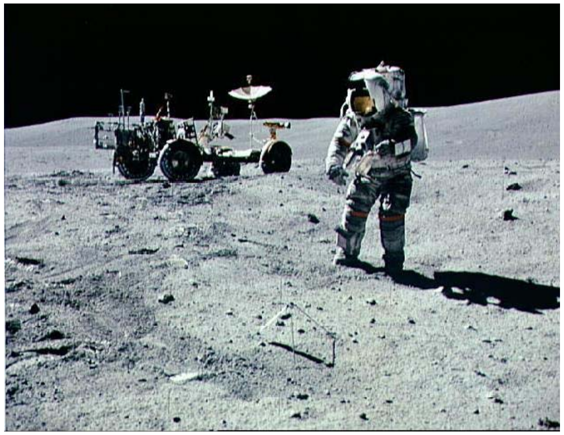
The acute affects in this table are cumulative. For example, a dose that causes damage to bone marrow will produce changes in blood chemistry and be accompanied by nausea. At a certain threshold every individual will experience these kinds of effects, which include nausea, skin reddening, sterility, and cataract formation.

Spaceflight Radiation Examples	
Human Spaceflight Mission Type	**Radiation Dose**
Space Shuttle Mission 41-C (8-day mission orbiting the Earth at 460 km)	5.59 mSv
Apollo 14 (9-day mission to the Moon)	11.4 mSv
Skylab 4 (87-day mission orbiting the Earth at 473 km)	178 mSv
International Space Station Mission (ISS) (up to 6 months orbiting Earth at 353 km)	160 mSv
Estimated Mars mission (3 years)	1200 mSv

How Can We Protect Astronauts?

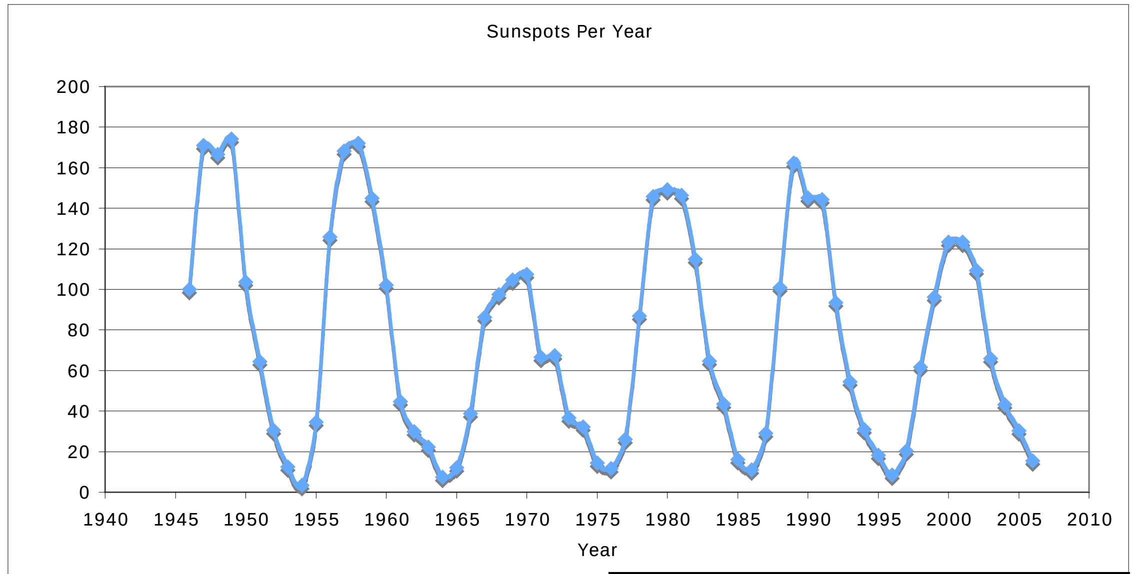
- Space weather forecasting
- Mission planning
- Shielding
- Radiation biology experiments
- Education

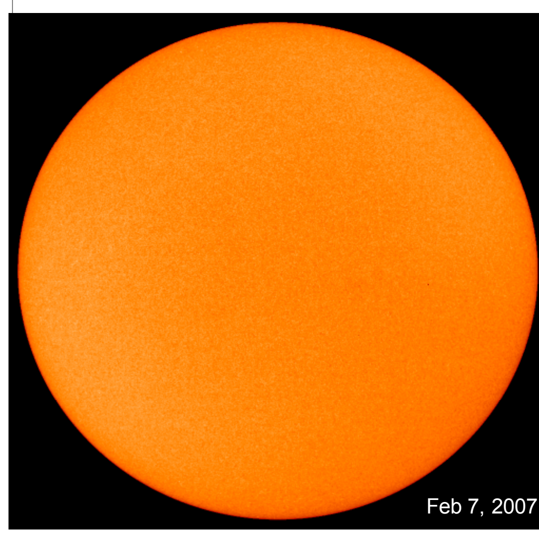


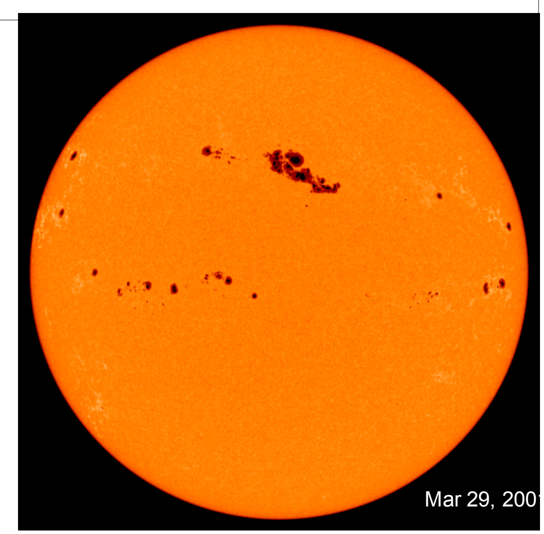


Solar Weather Forecasting

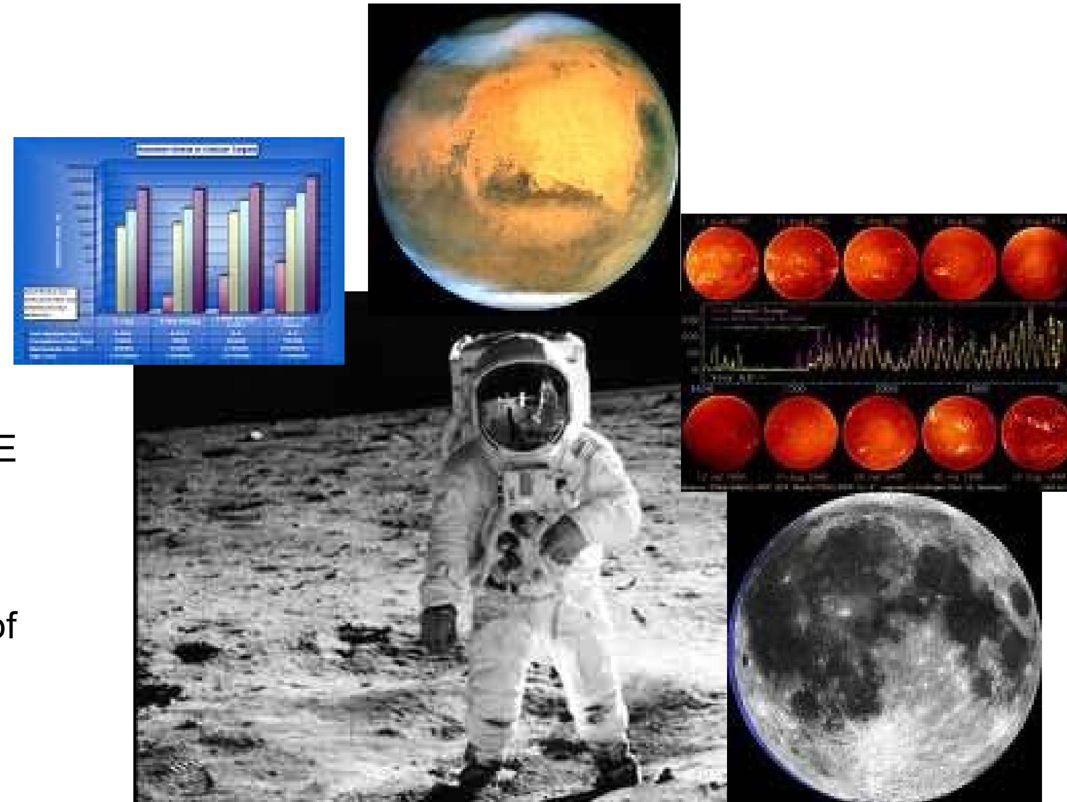
- Scientists can forecast when the Sun will be highly active (solar maximum).
- This is based on an 11-year solar cycle of sunspots.
- When the sun is at solar maximum, the Sun's magnetic field more effectively shields the solar system from galactic cosmic rays (GCR). GCR can be highly damaging to human tissues and spacecraft hardware.
- Predicting solar activity is very important when planning missions.





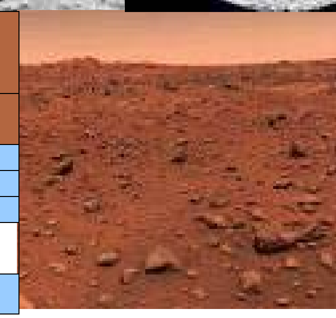


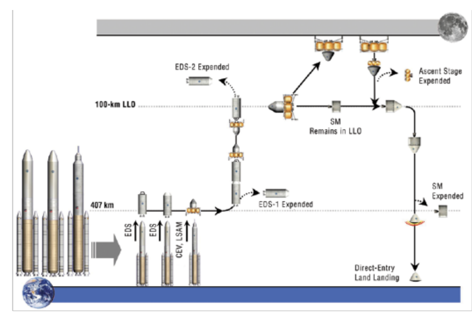
Mission Planning



- Planning missions at solar maximum will help to reduce GCR exposure, but risks of exposure to CME remain.
- Limiting the amount of time astronauts are outside of their spacecraft on Extravehicular Activities (EVAs) will help reduce overall radiation exposure.
- Projecting radiation exposure before the mission also helps mission planners anticipate how much time astronauts can be on EVA.
- Ensuring that astronauts have healthy diets on long missions is also very important.

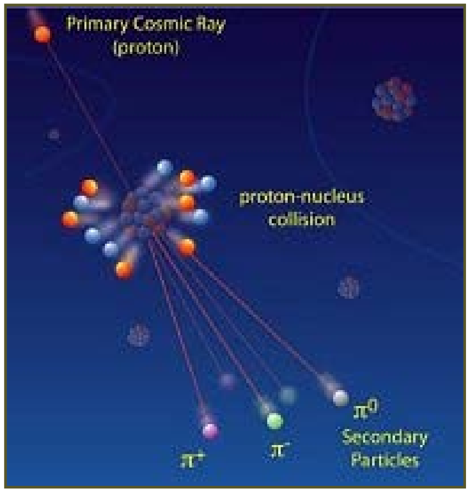
Radiation Exposure Limits for Astronauts and the General Public (in Sv)				
Type of person	**Time period**	**Organs (Sv)**	**Eye (Sv)**	**Skin (Sv)**
Astronauts	30-day	0.25	1.0	1.5
	Annual	0.5	2.0	3.0
	Career	1.0-4.0	4.0	6.0
Occupational Exposure	Annual	0.05	0.15	0.5
General Public	Annual	0.001	0.015	0.05



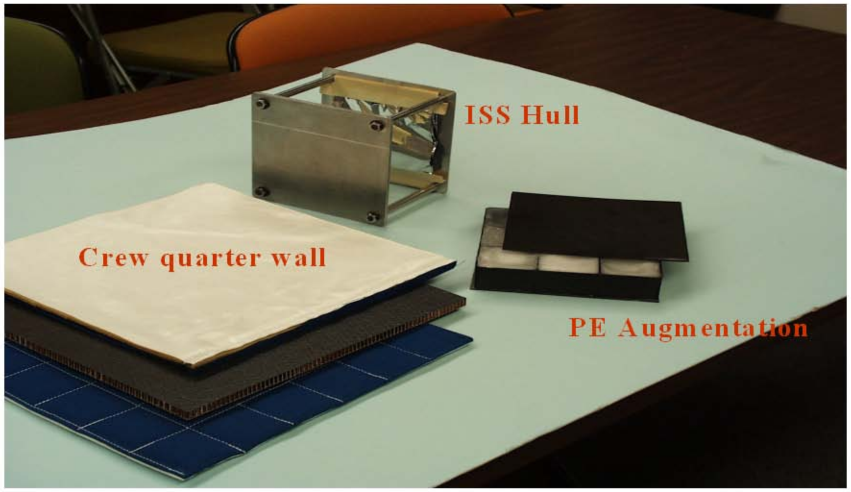


Shielding

- Incorporating strong, light, and hydrogen-rich shielding components such as water or polyethylene into spacecraft design will help absorb harmful radiation and protect the astronauts inside.

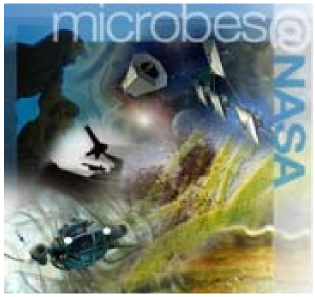


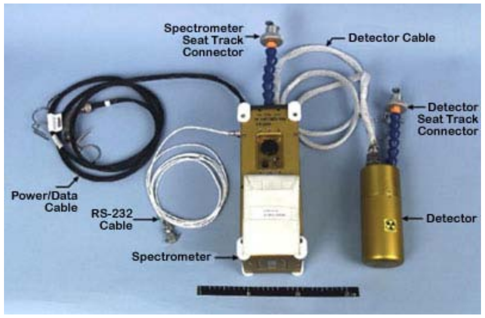
ISS hull and Crew Quarter wall with PE Augmentation



Radiation Biology Experiments

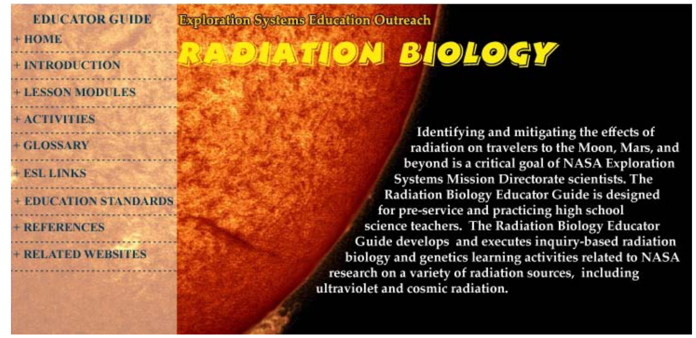
- Designing spaceflight and ground experiments to characterize the effects of radiation on small organisms will provide important information that will help scientists better understand the long term effects of acute and chronic space radiation exposure in humans.
- Measuring the radiation environment in and around spacecraft is also very important to understand the dose living organisms receive.





Education

- Educating both students and teachers in the concepts of radiation biology is important in training the next generation of space explorers.



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